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RESEARCH HIGHLIGHTS

December 2003

Technical Series 03-133

RESIDENTIAL COMBUSTION VENTING FAILURE – A SYSTEMS APPROACH

The research described in this Highlight took place many years ago, but it has never been released in a summary form. This Highlight has been written for distribution now because the findings of the research project are still valid and can still contribute to the understanding of the residential combustion spillage issue.

Introduction

There was growing concern in the 1980s that the Canadian housing stock was becoming more prone to combustion venting failures that could result in health- and/or life-threatening hazards. This perceived trend was due to a number of factors, including: the widespread conversion from oil heating to gas heating; decreasing frequency of furnace servicing; airtightness improvements in house envelopes; and increased use of powerful exhaust equipment, such as range-top barbeques. Improper venting of combustion gases from an appliance usually occurs when house depressurization overcomes chimney draft and reverses chimney flow.

This project was undertaken to meet the following broad objectives:

1. To improve understanding of combustion venting problems;
2. To determine the severity and occurrence of venting problems in Canada;
3. To develop improved techniques for identification and diagnosis of the venting problems;
4. To develop appropriate preventative and remedial measures; and
5. To identify ways to encourage and facilitate the implementation of these preventative and remedial measures.

Research Program

The work was divided into seven sub-projects, each of which is described briefly below.

Project 1: Cross-Country Survey of Over 1000 Houses

The purpose of the survey was to determine the incidence of spillage problems in the Canadian housing stock and to identify specific houses that experience significant spillage of combustion gases. A variety of spillage detectors were considered for the testing. The most convenient and economical technology was determined to be heat sensitive dots. These "dots", available for a range of temperatures, permanently change colour when their indicated temperature is exceeded. Different temperature dots were placed on furnaces and water heaters in such locations that the hot backdrafting air would cause the dots to change colour.

The dot detectors were installed in a total of 937 homes. After a two to three month monitoring period, all householders were interviewed by telephone; 808 surveys were successfully completed. A total of 121 houses were visited to confirm the results reported by homeowners. With only two exceptions, there were no major problems or inaccuracies with the homeowners' reports.

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Of the 606 gas-heated homes monitored, 10% were identified as "spillage houses", having experienced prolonged venting failure on at least one occasion. In the oil-heated houses, 72% were identified as spillage houses, with about 55% experiencing significant spillage. However, because the oil furnace detectors have a faster response time than the gas appliance detectors, some of these events may have involved only start-up spillage for durations of only 10 or 15 seconds.

Project 2: Modifications and Refinements to the Flue Simulator Model

The FLUESIM Model, at the start of this project, was a first-generation research tool developed to investigate interactions between components that lead to venting failure under circumstances that would not normally be considered hazardous. While the program was able to meet its objectives, improvements were needed to:

- refine accuracy;
- investigate more complex phenomena that appeared to have a critical role in determining venting performance;
- expand the capability of the model to encompass a wider variety of combustion devices and installation; and
- make the model easier to use.

In addition to the research team, a number of individuals reviewed the program and suggested improvements. As a result of the review, improvements/refinements were made to the program and the changes were validated with test data provided by Esso Canada Limited and Consumers Gas Limited. The user's manual was extensively revised to reflect the changes made to the program. Simulations then run using the program produced some useful information about causes of venting failures.

Project 3: Refinement of the Checklists

Over two years prior to the commencement of this project, CMHC set out to develop a checklist for householders to use in detecting and diagnosing potential backdrafting problems. Field trials of the checklist raised numerous technical and policy issues that could only be resolved through further research and development. This additional research lead to the development of separate procedures for identifying and diagnosing combustion venting problems; the separation of identification and diagnosis meant that the diagnostic tests could become more refined.

For a majority of houses, it was determined that emphasis would be placed on the use of inspections and/or warning devices instead of a checklist. The original checklist thus grew into five separate tests/procedures to assist tradesmen in diagnosing venting failures:

1. *Venting Systems Pre-Test*: a quick visual inspection procedure to identify the house as either likely or unlikely to experience backdrafting;
2. *Venting System Test*: a detailed test procedure to determine to what extent the combustion venting system is affected by the tightness of the building envelope;
3. *Chimney Performance Test*: a simple method of determining whether a chimney is capable of providing adequate draft;
4. *Heat Exchanger Test*: a quick method to determine if the heat exchanger of the furnace has a major leak;
5. *Chimney Safety Inspection*: a visual check for maintenance problems in the chimney.

Project 4: Hazard Assessment

The health and safety hazards associated with combustion venting failures in houses in Canada have never been well documented or investigated. The objective of this project was to provide a context for evaluating the severity of venting failures and to provide a means of expressing the results directly in terms of health risk. The work was divided into five tasks:

1. A review was conducted of the current knowledge on pollutant generation due to improper venting of combustion appliances.
2. A computer model was developed to predict pollutant concentrations in test houses and to assist in the investigations of case study houses.
3. A data acquisition system was assembled and calibrated. The system measured carbon monoxide, nitrogen dioxide, carbon dioxide, as well as temperatures around the dilution air inlet of furnaces and water heaters, indoor, outdoor and flue temperatures, indoor, outdoor and flue velocity pressures, and wind speed and direction.
4. Pollutant levels were monitored in 21 problem houses identified in the country-wide survey during simulated failure events.
5. The results were analyzed to arrive at an overall assessment of the health hazard represented by combustion venting failures in Canadian housing.

While comparison of empirical data collected during venting failure in a spillage house with the model's predictions for the same house showed reasonable agreement, further modeling of test houses in combination with monitoring is required to improve the predictive capabilities of the model. Unfortunately, without further study, it was not possible to assess the precise nature of the health and safety risks posed by spillage events.

Project 5: Remedial Measures

This project concentrated on research and testing of remedial measures to prevent pressure-induced spillage and included both make-up air supply measures and alternatives to make-up air supply. The work examined remedial measures for fireplaces, gas-fired appliances, oil furnaces, and make-up air supply.

For fireplaces, a spillage advisor (detector) was identified that, while not a remedial measure, could indicate to householders when spillage is occurring from their fireplace. Unfortunately, it was not possible to test the spillage advisor in actual use. In addition, a prototype airtight fireplace door was designed and fabricated for testing, the concept being that truly airtight doors can achieve significant separation of the fireplace from the house indoor pressure regime.

For gas-fired appliances, a temperature sensitive switch (Thermodisc type) was found to react consistently to spillage incidents and could be used to develop a number of different devices to warn of spillage. The "draft-assisting chamber", a proprietary device that attempts to prevent spillage by forcing combustion products downward against their natural buoyancy, was tested on a gas-fired furnace. While it did not significantly improve the time required to initiate proper flue flow, it did slightly increase the house depressurization limit (the pressure at which spillage occurs), although less than theoretically expected. For both gas and oil furnaces, a draft inducer fan was found to be very effective in preventing spillage. The elimination of the barometric damper in an oil furnace, combined with the installation of a high-pressure burner and insulated chimney, was evaluated. While the draft was slightly improved, the margin of improvement was not as great as with the induced draft fan and the cost of this retrofit is quite high. A solenoid delay valve, which allows the fan on an oil burner to activate before the oil flow is started, was not found to be particularly effective.

Testing on a 1960s vintage bungalow in Saskatoon found that the provision of additional supply air is not likely to be effective as a remedy for pressure-induced spillage unless a supply air fan is used; also, to be effective, the supply air fan must have a capacity at least equal to the total capacity of all exhaust equipment it is attempting to counteract.

The knowledge gained through this research was synthesized into a manual intended to be a decision-making guide for tradesmen and contractors who have identified pressure-induced spillage problems in houses with vented fuel-fired appliances and want to know how best to remedy these problems. The guide describes seven measures: make-up air ducts; warning devices; induced draft fan; blast fan; sealed and adjusted forced air ductwork; flue tightening, flue insulating and delayed ignition; and airtight doors and direct air supply for fireplaces.

Project 6: Problem House Follow-up

Testing and monitoring of 21 houses identified in the cross-country survey as experiencing spillage problems was carried out in the late portion of the project to weave together in a cohesive way all the sub-projects, and to clarify many of the issues that had been addressed elsewhere. The objectives were:

- To categorize and quantify the nature of venting failures in the context of the country-wide survey;
- To isolate contributing factors;
- To collect field data on venting failures for use in the FLUE SIMULATOR model validation;
- To measure the frequency and quantity of spillage in problem houses;
- To measure the approximate impact on air quality of venting failures in houses;
- To evaluate the effectiveness of the chimney safety tests in diagnosis of failures and identification r remedial measures;
- To evaluate communications techniques; and
- To evaluate remedial measures under field conditions.

Project 7: Communications Strategy

Some of the work completed as part of this sub-project included the development of a network of interested agencies, a training workshop on the use of the FLUESIM program, and a one-day pilot training course on the chimney safety tests. However, the culmination of this project was the development of a communications strategy to "encourage and facilitate action appropriate to the problem incidence and severity identified". As the research revealed that the problem, while substantial, is not epidemic in proportion, there was no need to create widespread alarm in the general public. However, to raise awareness of the venting problem, the need remained for the development of a follow-up communications strategy, including the following key elements:

- Direct distribution of the summary report to key government and industry officials;
- Distribution of the summary report to key media outlets serving the industry and general public;
- Distribution of the FLUESIM model to appropriate users;
- Further development and promotion of the chimney safety tests, including transfer of the chimney safety test

training to industry groups, such as HRAI, NECA and CHBA;

- Distribution of the householder venting safety checklist and development of further consumer information materials;
- Liaison with relevant government agencies, standard-setting agencies and code authorities to encourage coordinated action; and
- Development of a longer-term communications strategy to promote full implementation of the chimney safety tests and remedial measures.

Research Results

The country-wide survey, the follow-up inspections and the hazard assessment have yielded a first indication that the occurrence of combustion spillage in houses is widespread, but the consequence of these episodes is not immediately severe in most cases. The survey and field testing highlighted a number of combinations of causes of venting failure that had not been fully appreciated previously. For instance, some chimneys produce such low draft that even small depressurizations of the house can produce prolonged spillage and/or backdrafting. The combination of a weak chimney with an airtightened building envelope is now thought to be an important cause of the relatively high incidence of venting problems in pre-1945 housing stock – a portion of the stock that was presumed to be relatively free of venting problems before the survey.

The case studies revealed the "systems" nature of the problem, in that most case study houses had several factors that contributed to their combustion venting problems. Modeling using the FLUESIM program confirmed this result, by showing that venting problems with a chimney depend not only on its own characteristics and location, but also on the circumstances in which it is required to operate. For example, stand-by times can dramatically influence performance. Also, exterior chimneys typically produce very low drafts due to the cooling nature of cold exterior air leaking into the flue. Further, the FLUESIM program has been developed to be user-friendly with an extensive user manual and can be extremely useful in helping to prevent circumstances that may lead to venting problems.

The survey results, the modeling, the remedial measures research and the case studies all indicate that spillage from conventional fireplaces is virtually certain in all but the leakiest houses and that conventional glass doors provide no additional protection against this spillage. It was also found that spillage from low ember wood fires will sometimes not be detected by an ionization type smoke alarm due to the low particle density. To detect spillage from low ember fires, it was found necessary to use a carbon monoxide detector in combination with a smoke detector mounted at the level of the mantle.

A variety of effective preventative and remedial measures have emerged from the project, including the draft inducer for gas and oil furnaces, the high pressure burner and solenoid for oil furnaces and truly airtight doors for fireplaces. All these remedial measures are now recorded in a manner useable to trades persons in the draft Remedial Measures Manual. Detection devices were also investigated that, although they will not prevent combustion venting problems, when connected to alarms or warning devices, they can prevent a venting problem from becoming a health problem. In addition, some remedial measures have been found to be less effective. For example, retrofitting a chimney by installing a liner without also reducing the firing rate of the appliance may also result in prolonged combustion gas spillage. Further, this project has made it clear that simply putting a hole in the building envelope to supply make-up air will typically not be sufficient to prevent or remedy venting problems, as the hole would need to be too large to be practical.

Implications for the Housing Industry

Because the potential for combustion gas spillage is estimated to be high in a significant portion of the Canadian housing stock, there is a responsibility placed on the housing and heating industries to improve the margin of safety against life- or health-threatening combustion venting failures. This can be accomplished by designing, installing and maintaining heating appliances to burn as cleanly as possible and by reducing the factors in the interfacing of heating appliances, venting systems and houses which lead to combustion venting failures. The vastly differing ranges of climate in Canada and the broad range of construction practice of Canadian houses, mean that no single recommendation can be made that applies cost-effectively for all types of installations. However, the FLUESIM program can be useful in evaluating such parameters to find an appropriate solution.

Through this research, significant strides were made in developing an improved understanding of the combustion venting problem. A staged approach to identifying and diagnosing venting problems was developed and tested and found to provide a reliable approach to finding and diagnosing the cause of combustion failure accurately and cost-effectively. A variety of preventative and remedial measures emerged from the project. However, perhaps the most fundamental preventative measure was the improved understanding of the combustion

venting process. This project, and similar projects by other agencies, led to an increase in the knowledge and awareness of house depressurization problems. The research findings have since been integrated into building codes, equipment standards, and heating and ventilating industry training. Much of the trend to draft-assisted equipment is due to these research findings.

Project Manager: Don Fugler

Research Report: *Residential Combustion Venting Failure – A Systems Approach: Summary Report, 1987, 145 pages.*

Research Consultant: Scanada Consultants Limited and Sheltair Scientific Inc.

Housing Research at CMHC

Under Part IX of the National Housing Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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